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The Viscosities of Roofing Asphalts at Application Temperatures

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The Viscosities of Roofing Asphalts at Application Temperatures

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The Viscosities of Roofing Asphalts at Application Temperatures

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The optimum range of kinematic viscosity over which hot asphalt should be applied in the fabrication of built-up roofing membranes was determined to be 50 to 150 centistokes (mm^2/s). This viscosity range was based on the relationship between interply thickness and application temperature of asphalt obtained from roofing membrane specimens fabricated in the field. Because laboratory measurements showed a wide range of viscosities for roofing asphalts of the same type over their application temperature ranges, it was recommended that asphalts be applied at temperatures based on viscosity and not empirically determined temperature limits. In practice, the viscosity-temperature relationship should be determined for each roofing asphalt for the application temperature range prior to use. Using this relationship and the optimum viscosity range, the temperature range for applying each asphalt can be determined.

Key words: Application temperature; asphalt; built-up roofing; interply thickness; roofing membranes; viscosity.

1. Introduction

More than 95 percent of built-up roofing membranes are constructed using asphalt as the between-ply bitumen and flood coat [1][1]. The built-up membranes are generally constructed by applying hot asphalt in consecutive, solid layers to adhere roofing felts to each other in shingle fashion. The temperature range over which the hot asphalt is applied has been traditionally determined empirically. Asphalt at temperatures within this range, considering ambient temperature and wind conditions, is expected to be fluid and readily applied. In addition to an application temperature range of asphalt, a maximum temperature to which the asphalt may be heated is specified. This maximum specified temperature is intended to prevent flashing of the asphalt and deleterious changes in the asphalt's physical and chemical properties. Unfortunately, the minimum and maximum temperature requirements pertaining to the application of asphalt are not based on scientific or technical evidence. The fundamental property of asphalt on which the application temperature should be based is viscosity. Viscosity is the property of the asphalt which governs its flow.

1.1. Objective

The objective of the research was to develop a viscosity criterion for the application of asphalt in the fabrication of built-up roofing membranes. The research project was divided into two phases. In the first phase, viscosity-temperature relationships were determined for Type I and Type III asphalts, ASTM Designation D312–71 [2], for the normal temperature range of application. The asphalts represented a variety of sources and blends commonly used by the roofing industry in the United States. In the second phase, 3-ply built-up roofing membrane specimens were prepared in the field with asphalts at temperatures that ranged from 325 to 500°F (163 to 260°C). The thicknesses of the between-ply asphalt were measured and related to the application temperatures and to the viscosities of the asphalts at those temperatures. Based on the results of the viscosity-temperature relationships and the between-ply thicknesses of the asphalts, a viscosity criterion for applying hot asphalt was recommended.

1.2. Function of Asphalt in Built-Up Roofing Membranes

The function of the asphalt in the asphalt-felt built-up roofing membrane is twofold [3]. The asphalt is an adhesive for bonding the felts and provides a waterproofing layer between the felts. Applying the asphalt at a temperature within an empirically determined temperature range does not assure that the hot asphalt will flow properly to provide adequate adhesion and waterproofing. Therefore, to attain these essential properties, the viscosity of the roofing asphalt during application should be specified.

Proper flow of the asphalt is a necessity during the membrane fabrication process. If the asphalt is too viscous, it will not flow readily enough to penetrate the felts, and may be too thick, uneven and possibly cause interply voids. Poor penetration into the felts, and a thick or uneven application can result in poor adhesion between plies. Excessive thickness of between-ply asphalt under certain conditions may contribute to roofing failure by membrane slippage [4] or excessive thermal movement. In addition, too thick an application of the asphalt is a waste of a petroleum based material. Voids which may trap water are potential sources of blisters.

If the asphalt is too fluid during application, it will flow too readily resulting in a layer of asphalt which may be too thin. An application which is too thin may result in poor adhesion, voids and inadequate waterproofing between felts.

[1] Figures in brackets indicate references listed in section 7.

1.3. Application Specification

Roofing asphalts are classified in ASTM Standard D312–71 into four types, I, II, III, and IV, by empirical tests such as softening point, ductility and pentration [2]. These tests are not a measure of the flow of roofing asphalt at application temperatures. They may give a relative indication of this property for the various types. A Type I asphalt has a lower softening point and may have a higher penetration than a Type III asphalt. At a given application temperature it would be expected that a Type I asphalt would in general flow more readily than a Type III asphalt.

Current specifications for applying hot asphalt do not consider differences in flow properties for different asphalts. For example, the National Roofing Contractors Association (NRCA) lists in their manual [5] the same range of application temperatures for all four types of asphalts. They recommend a minimum application temperature of 350 °F (177°C) and a maximum heating temperature of 475 °F (246°C).

Likewise, in the Tri-Service manual, "Maintenance and Repair of Roofs," it is stated that "asphalt should not be heated above 450 °F (232°C) and should normally be not lower than 350 °F (177°C) when poured or mopped on a roof [6]." This statement ignores differences in flow of the four types of asphalts at a given temperature. Some recognition of the flow phenomenon is made as this Tri-Service manual further states that "if asphalt with a softening point of 150 °F (66°C) or lower is used, the maximum kettle temperature is 375 °F (191°C) and the minimum temperature for application is 300 °F (149°C)."

Manufacturers of bituminous roofing felts recommend in general a minimum application temperature and a maximum heating temperature for roofing asphalts. Some of the manufacturers recommend lower minimum and maximum temperatures for Type I than for Type III asphalts. The latter recommendation acknowledges differences in flow properties between the two types.

1.4. Viscosity of Roofing Asphalts

One session of the Fourth National Conference on Roofing Technology, sponsored by the National Bureau of Standards (NBS) and the National Roofing Contractors Association (NRCA) in 1975, discussed viscosity grading of roofing asphalt. Cullen briefly reported the conclusion of that session [3]. It was stated that the hot asphalt should be applied with a viscosity of approximately 150 centistokes (mm^2/s). In addition, Mertz has stated that the optimum application viscosity is 100–150 centistokes (mm^2/s) under good weather conditions which he defined as 60 °F (16°C) and above [7].

Viscosity grading of asphalt is not a new concept. Viscosity specifications have been used for a number of years for paving asphalts. This subject is reviewed in ASTM STP 532, "Viscosity Testing of Asphalt and Experience with Viscosity Graded Specification [8]."

A viscosity grading criterion for the application of asphalt in the fabrication of a built-up roofing membrane would help to assure proper application of the hot asphalt. The asphalt would be applied at a temperature to achieve adequate bonding of the felts and a continuous waterproofing layer of asphalt between the felts. Membrane failures caused by inadequate interply adhesion would be reduced. Roofing performance would be enhanced and asphalt would be conserved due to a reduction in excessively thick applications.

2. Experimental Program

The experimental program consisted of two phases. The first phase was concerned with the measurement of the viscosities of a wide variety of typical roofing asphalts from many sources throughout the world. These measurements were intended to provide information on the range of viscosity-temperature relationships which may be expected for roofing asphalts from different sources and blends.

In the second phase of the experimental program, the between-ply thicknesses of asphalts in roofing membranes were related to the viscosities of the asphalts at the time of application. Viscosity-temperature relationships were also determined for the two types of asphalts, Types I and III, used in the fabrication of built-up roofing membrane specimens.

2.1. Measurement of Asphalt Viscosity

2.1.1. Asphalt Samples

The National Roofing Contractors Association selected the twenty asphalt samples used in the study to determine the range of viscosity-temperature relationships of roofing asphalts. The twenty asphalt samples, ten each of ASTM D312–71 Type I and Type III [2], were made available to the National Bureau of Standards by the Trumbull Asphalt Company. These asphalt samples, from various sources throughout the world, were typical of the broad range of asphalts currently used in roofing in the United States. Four of the samples were blends of asphalts from two sources. Table 1 lists the asphalts along with their sources, softening points, penetration and experimentally determined kinematic viscosities.

The properties of the asphalts used to prepare the built-up roofing membrane specimens are given in table 2. The properties of the asphalts, softening point, penetration and kinematic viscosity, were determined for the two types of asphalt from samples collected both before and after fabrication of the membrane specimens.

2.1.2. Test Method

Measurements of the viscosities of the asphalt samples were performed according to the procedure described in ASTM D2170–74, "Standard Method of Test for Kinematic Viscosity of Asphalts (Bitumens) [9]." The test method consists of measuring the time required for the asphalt to flow through a constant vol-

TABLE 1. *Sources and properties of asphalt samples*

Designation	Source	Refinery	Type	ASTM—D 312 Designation			Viscosity[b,c], Centistokes	(mm²/s)	
				Softening Point[a]		Penetration[a] $\times 10^{-1}$ mm	330 °F (166°C)	380 °F (193°C)	430 °F (221°C)
				°F	°C				
1	Venezuela	Jacksonville	I	140	60	38	275	98	48
2	California	Portland	I	140	60	34	124	48	24
3	Wyoming	([d])	I	146	63	31	238	87	39
4	Kuwait-Venezuelan Blend	Morehead City	I	145	63	28	248	88	41
5	Kansas	Hazelwood	I	144	62	27	197	74	36
6	Persian Gulf	Waltham	I	144	62	37	254	92	44
7	Oklahoma	Irving	I	141	61	33	203	77	([e])
8	West Texas	Houston	I	140	60	32	154	60	30
9	Gulf Coast	Detroit	I	144	62	28	220	81	43
10	California	Compton	I	142	61	24	189	69	32
11	California (50%) Persian Gulf (50%)	Portland	III	199	93	16	1272	313	118
12	Texas Coast	Jacksonville	III	202	94	28	830	208	76
13	Wyoming	([d])	III	204	95	30	456	104	41
14	Kuwait-Venezuelan Blend	Morehead City	III	191	88	17	1243	333	141
15	West Texas	Houston	III	202	94	20	811	213	82
16	Kansas	Hazelwood	III	199	93	22	1369	318	118
17	Venezuela (50%) Persian Gulf (50%)	Waltham	III	197	91	23	1175	311	121
18	Oklahoma	Irving	III	201	94	24	1383	322	124
19	Gulf Coast	Detroit	III	198	92	20	650	170	66
20	Persian Gulf	Compton	III	200	93	18	1154	291	92

[a] Values of softening point and penetration were furnished by the Trumbull Asphalt Company.

[b] Viscosity determined as described in ASTM Standard D2170-74.

[c] The viscosities are the averages of three measurements. The relative standard deviation for each average value was 3 percent or less except for four values. The relative standard deviations for sample 4 at 330 °F (166°C), sample 16 at 330 °F (166°C), sample 9 at 330 °F (166°C) and sample 9 at 430 °F (221°C) were 4, 5, 7 and 8 percent, respectively.

[d] The refinery of this asphalt was not provided to NBS.

[e] Viscosity determination not valid at this temperature because asphalt liberated a gas which was trapped in the capillary tube of the viscometer.

ume in a calibrated capillary viscometer under a constant pressure and at a constant temperature. The calibrated viscometer has a viscosity constant, in units of centistokes per second (mm²/s²), obtained by measuring the flow time of a standard liquid of known viscosity. The viscosity of the asphalt, in centistokes (mm²/s), is determined by multiplying its flow time, in seconds, by the calibration constant of the viscometer.

Zeitfuchs cross-arm viscometers, shown in figure 1, were the type of capillary viscometers used in this study. Five sizes of these viscometers (sizes 4 through 8) having different inside capillary tube diameters were used to measure viscosity depending on the rate of flow of the asphalt [9]. The time for the asphalt to flow through a constant volume in the viscometers ranged from about 60 to 180 seconds. The values of viscosity of the asphalts listed in tables 1 and 2 are the average of three measurements. Each of the three measurements for a particular asphalt at a given temperature was made using a different viscometer of the same size.

A silicone oil bath was the constant temperature medium for the viscosity measurements. The bath was capable of maintaining the temperature within ±0.1 °F (±0.05°C) of the selected test temperature.

Cleaning the viscometers presented some difficulty and was time consuming. In general, the viscometers were removed from the oil bath, rinsed until clean with a solvent such as tetrachloroethylene and dried in an oven at 350 °F (177°C). The capillary tubing of the viscometer must be clean prior to test in order to obtain valid results.

2.2. Interply Asphalt Thickness of Built-Up Roofing Membrane Specimens

2.2.1. Fabrication of Membrane Specimens

The preparation of the membrane specimens under field conditions was performed in Kansas City, Missouri, with the cooperation of the Roofers Local #20 Joint Apprenticeship Program. National Bureau of Standards personnel planned and supervised the field

Table 2. *Properties of asphalts used to prepare built-up roofing membrane specimens*

Asphalt[a]	Physical Properties[b]			Viscosity[c,d], Centistokes (mm^2/s)					
	Softening Point[e]		Penetration[f]	325 °F (163°C)	350 °F (177°C)	375 °F (191°C)	400 °F (207°C)	425 °F (219°C)	450 °F (232°C)
	°F	°C	$\times 10^{-1}$ mm						
ASTM Type I—sample collected before mopping specimens	143	61	41	226	134	83	56	37	28
ASTM Type I—sample collected after mopping specimens	141	60	42	207	123	77	52	36	26
ASTM Type III—sample collected before mopping specimens	190	88	28	849	403	215	130	80	56
ASTM Type III—sample collected after mopping specimens	189	87	28	802	386	206	124	78	53

[a] Asphalt type described in ASTM D312-71.
[b] Physical properties determined by the National Bureau of Standards.
[c] Viscosity determined as described in ASTM Standard D2170-74.
[d] The viscosities are the averages of three measurements. The relative standard deviation for each average value was 3 percent or less.
[e] Softening point determined as described in ASTM Standard D2398-71.
[f] Penetration determined as described in ASTM Standard D5-73.

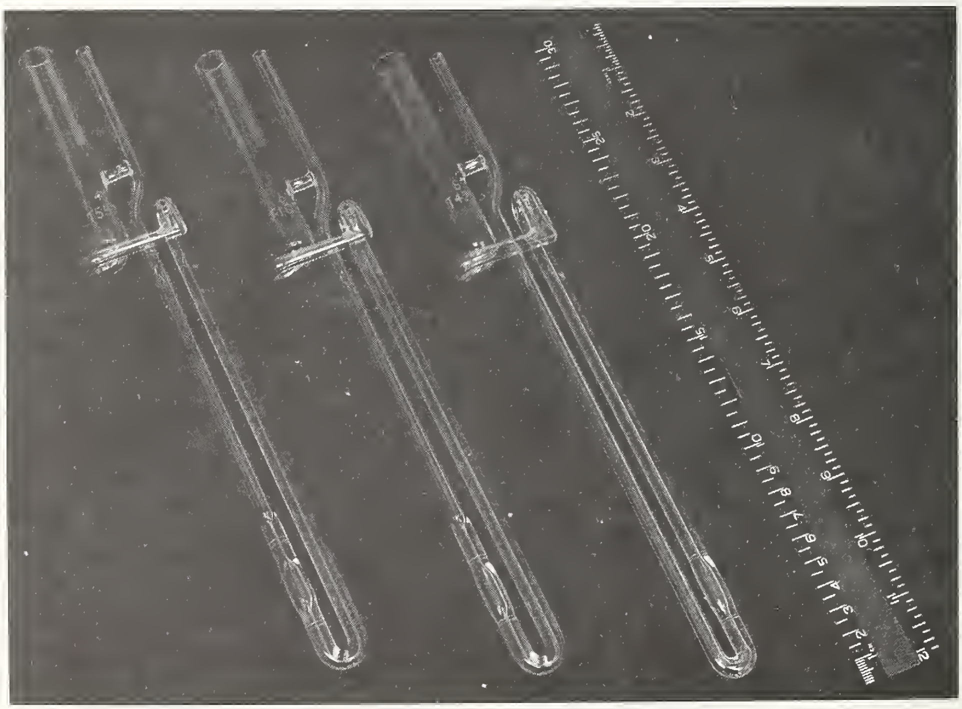

Figure 1. *Zeitfuchs cross-arm viscometers, sizes 4, 6 and 8.*

study. The Joint Apprenticeship Program obtained the materials and equipment needed to prepare the membrane specimens, and provided the use of their facilities for membrane fabrication at the Kansas City Technical Education Center. Apprentice roofers performed the mopping under the direction of journeymen roofers. The membranes were fabricated inside the building where the temperature was about 60 °F (16°C). The bottom plies of the membrane specimens were not bonded to the substrate over which membrane preparation took place.

Six types of 3-ply membrane specimens measuring 3 x 9 ft (0.9 x 2.7 m) were prepared from organic, asbestos and glass roofing felts, and ASTM Type I and Type III asphalts, respectively. The materials used in the preparation of the membrane specimens are listed in table 3. Membrane specimens were fabricated using each type of roofing felt and each type of asphalt which was applied at temperatures that ranged from 325 to 500 °F (163 to 260°C) in approximately 25 °F (14°C) temperature increments. In general two membrane specimens were fabricated at each of these mopping temperatures. In some cases, there was a difference in the mopping temperatures of asphalt for two comparable specimens. Tables 4 and 5 list the temperatures of the asphalt at which each specimen was fabricated. A total of 95 membrane specimens were prepared; 32 from organic felt, 32 from glass felt and 31 from asbestos felt.

Table 3. *Materials used in preparation of the built-up roofing membrane specimens*

Materials	ASTM Specification
Asphalt—Type I	D312-71
Asphalt—Type III	D312-71
Asphalt saturated organic felt—Type 15	D226-75
Asphalt saturated asbestos felt—Type 15	D250-70
Asphalt-impregnated glass fiber mat—Type 15	D2178-69

The temperature of the asphalt in the mopping bucket was recorded immediately prior to application to the felts. A copper-constantan thermocouple and a digital thermocouple indicator were used to measure the temperature of the asphalt. The asphalt was transferred from the heating kettle, which was located outside of the building, to the mopping bucket at a temperature that was higher than the selected application temperature. The asphalt was allowed to cool in the

Table 4. *Asphalt application temperatures, average interply asphalt thickness and calculated asphalt viscosities for built-up roofing membrane specimens fabricated with type I asphalt.*

Type of felt in membrane specimen	Number of specimens	Application Temperature		Interply Thickness[a]		Calculated asphalt viscosity centistokes (mm^2/s)
		°F	°C	in	mm	
Organic	2	325	163	0.039	0.99	226
	2	352	178	.030	.76	127
	2	379	193	.023	.58	77
	2	401	205	.022	.56	54
	2	428	220	.022	.56	36
	2	455	235	.015	.38	26
	2	477	247	.022	.56	20
	2	500	260	.018	.46	16
Asbestos	2	327	164	.041	1.04	217
	2	354	179	.032	0.81	123
	2	379	193	.036	.91	77
	2	403	206	.031	.79	53
	2	426	219	.023	.58	37
	2	455	235	.024	.58	26
	2	477	247	.024	.61	20
	2	505	263	.021	.53	15
Glass	2	325	163	.037	.94	226
	2	351	177	.032	.81	132
	2	378	192	.022	.56	80
	2	403	206	.019	.48	53
	2	428	220	.020	.51	36
	2	446	230	.018	.46	29
	2	477	247	.021	.53	20
	2	502	261	.019	.48	15

[a] The value of interply thickness for each membrane specimen represents the average of 24 measurements. The mean relative standard deviation of the average interply thickness determinations in tables 4 and 5 was 31 percent. Eighty percent of the relative standard deviations fell within the range of 15 to 45 percent. The minimum and maximum relative standard deviations were 9 and 61 percent, respectively.

Table 5. *Asphalt application temperatures, average interply asphalt thicknesses and calculated asphalt viscosities for built-up roofing membrane specimens fabricated with type III asphalt*

Type of felt in membrane specimen	Number of specimens	Application Temperature		Interply Thickness[a]		Calculated asphalt viscosity centistokes (mm^2/s)
		°F	°C	in	mm	
Organic	2	323	162	0.057	1.45	887
	2	343	173	.058	1.47	503
	2	374	190	.043	1.09	233
	2	392	200	.051	1.30	156
	2	424	218	.054	1.37	82
	2	482	250	.030	0.76	33
	2	484	251	.027	.69	32
	2	500	260	.019	.48	26
Asbestos	2	329	165	.055	1.40	755
	2	343	173	.062	1.57	503
	1	376	191	.056	1.42	224
	1	379	193	.064	1.63	206
	1	399	204	.051	1.30	134
	1	403	206	.047	1.19	125
	1	426	219	.046	1.17	80
	1	455	235	.032	0.81	49
	1	457	236	.048	1.22	48
	2	482	250	.051	1.30	33
	2	489	254	.020	0.51	30
Glass	1	322	161	.049	1.24	936
	1	331	166	.051	1.30	717
	2	342	172	.051	1.30	529
	1	378	192	.045	1.14	215
	1	385	196	.043	1.09	183
	1	392	200	.041	1.04	156
	1	397	203	.050	1.27	139
	1	426	219	.044	1.12	80
	1	428	220	.036	0.91	77
	2	466	241	.027	0.69	42
	2	471	244	.034	.84	38
	2	500	260	021	.53	26

[a] The value of interply thickness for each membrane specimen represents the average of 24 measurements. The mean relative standard deviation of the average interply thickness determinations in tables 4 and 5 was 31 percent. Eighty percent of the relative standard deviations fell within the range of 15 to 45 percent. The minimum and maximum relative standard deviations were 9 and 61 percent, respectively.

mopping bucket until the desired application temperature was reached. The temperature of the asphalt was recorded only before mopping the bottom felts.

In the preparation of the membrane specimens, the bottom felts were mopped with hot asphalt and the second plies of felt were immediately laid in the hot asphalt. The top plies were laid in the same manner after mopping the second plies of felt. Two comparable membrane specimens were mopped at the same time. The membrane specimens were prepared in "sandwich" fashion by laying one 3 x 9 ft (0.9 x 2.7 m) piece of felt directly over another. This type of membrane fabrication differed from the usual field method of "shingle" application of roofing felts. The felts were laid with care and smoothed out by hand. Brooming of felts was not carried out because this procedure might have affected the flow of the hot asphalt and influenced the between-ply thickness of the asphalt. The experiment was designed to measure the between-ply bitumen thickness as a function of asphalt flow and not of pressure applied to the felts.

One gallon (3.8 dm^3) samples of the Type I and Type III asphalts were collected both before and after membrane fabrication. These samples were sent to the National Bureau of Standards laboratories for the purpose of measuring their viscosities over the range of application temperatures.

2.2.2. Sampling of the Membrane Specimens

The 3 x 9 ft (0.9 x 2.7 m) membrane specimens were too large for shipment to the National Bureau of Standards laboratories and for measurements of the interply asphalt thickness. Therefore, six 6 x 12 in (152 x 305 mm) coupon samples were randomly sampled from each of the large membrane specimens. The random sampling procedure was determined by the National Bureau of Standards' Statistical Engineering Laboratory.

Each membrane specimen was divided into six equal 1½ x 3 ft (0.5 x 0.9 m) sections. Each section was divided further into nine equal 6 x 12 in (152 x

305 mm) subsections. One subsection coupon from each section of each membrane was randomly cut, thus providing the six coupon samples from each membrane specimen. Figure 2 shows a typical random sampling pattern for the selection of six coupon samples from a membrane specimen. A total of 570 coupon samples was sent to the National Bureau of Standards laboratories for determination of the interply asphalt thickness.

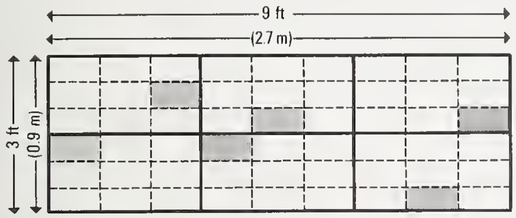

FIGURE 2. *Typical random sampling pattern for the selection of six coupon samples from a membrane specimen.*

2.2.3. Measurement of the Interply Asphalt Thickness

The interply thicknesses of the asphalt in the field mopped specimens were determined with the use of a 20-power machinist's microscope. A ½ x 12 in (13 x 305 mm) strip was cut from each of the coupon samples. Each strip was placed on edge under the lens of the microscope and the interply bitumen thickness was measured in units of 0.001 in (0.025 mm). Four thickness measurements were made for each strip, two for each between-ply mopping. The measurements were made at distances of approximately 4 and 8 inches (102 and 203 mm) from one end along the edge of the strip. Figure 3 shows a membrane strip mounted under the lens of the microscope.

The microscope base on which the membrane strip was mounted was movable and the movement could be read directly in 0.001 in (0.025 mm) using a micrometer. A cross-hair in the eye piece of the microscope was aligned on one asphalt/felt interface. The microscope base supporting the sample was then moved until the cross-hair passed over the interply asphalt and was aligned on the opposite asphalt/felt interface. The interply thicknesses of the asphalt were determined from the differences in the micrometer readings.

A total of 24 measurements were made to determine the interply thicknesses of asphalt in each membrane specimen. since there were six coupon samples cut from each membrane specimen.

3. Results

3.1. Measurement of Asphalt Viscosity

The viscosities of the 10 Type I and 10 Type III asphalts were determined at 330, 380 and 430 °F (166, 193 and 221°C) to determine the range of viscosity-

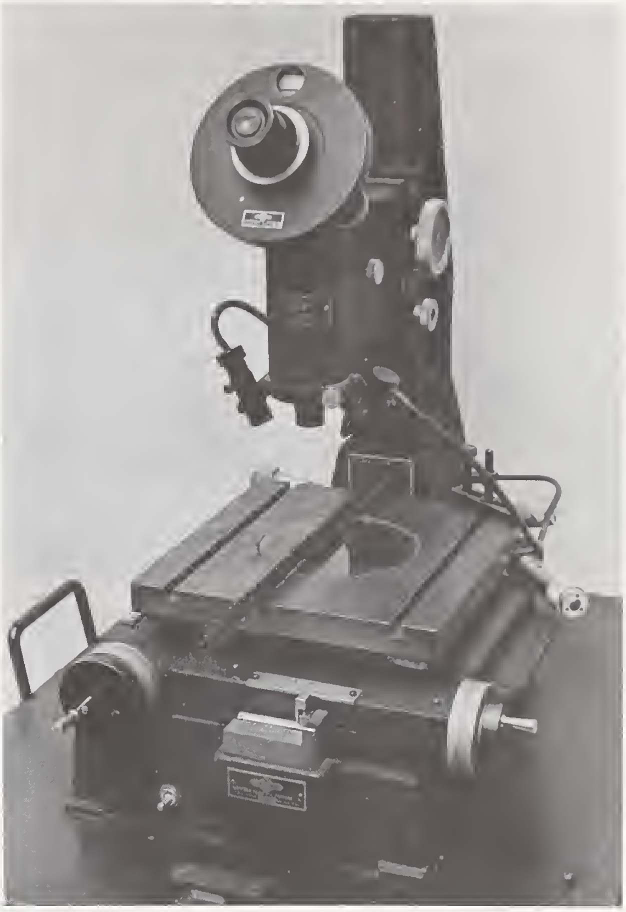

FIGURE 3. *Measurement of interply asphalt thickness using a machinist's microscope.*

temperature relationships of typical roofing asphalts. The viscosities are given in table 1 and the ranges in which they fell are illustrated graphically in figure 4. The viscosity data may also be illustrated according to ASTM D341–74 which is a method for plotting the log log viscosity versus the log absolute temperature [10]. Such plots for the most viscous and least viscous asphalts given in table 1 approximated straight lines as shown in figure 5. It is noted that for asphalt designated as number 7 in table 1, the viscosity determination at 430 °F (221°C) was not valid because the asphalt liberated a gas, observed as bubbles entrapped in the capillary tubing of the viscometer. These entrapped bubbles caused an erratic, nonreproducible flow of asphalt.

An attempt was made to measure the viscosity of the asphalts at 480 °F (249°C), but the test method was not suitable with these asphalt samples at this high temperature because of the gas bubbles which formed within the capillary tubes of the viscometers. At temperatures in the range of 325 to 450 °F (163 to 232°C), the test method was in general readily applied to the measurement of the viscosities of these roofing asphalts.

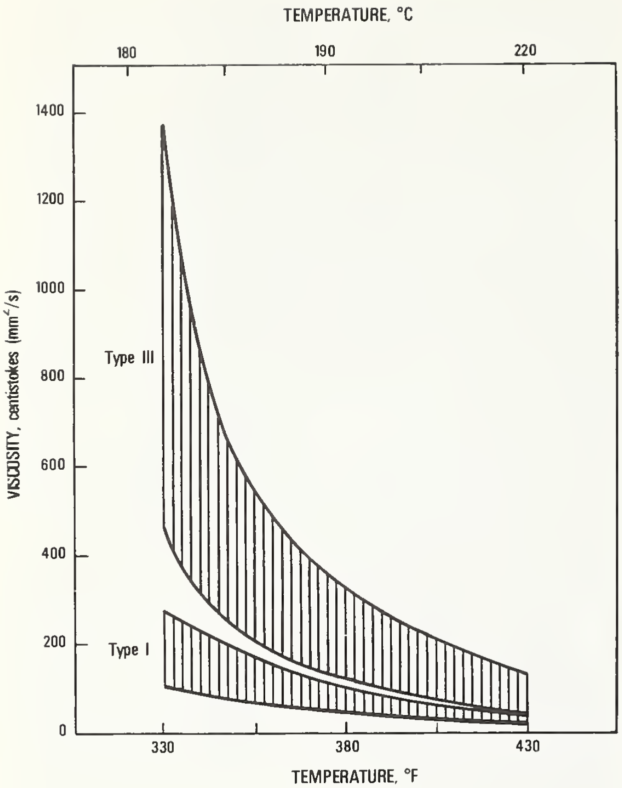

FIGURE 4. *Ranges of the viscosity-temperature relationships for the Type I and Type III asphalts obtained from various sources throughout the world.*

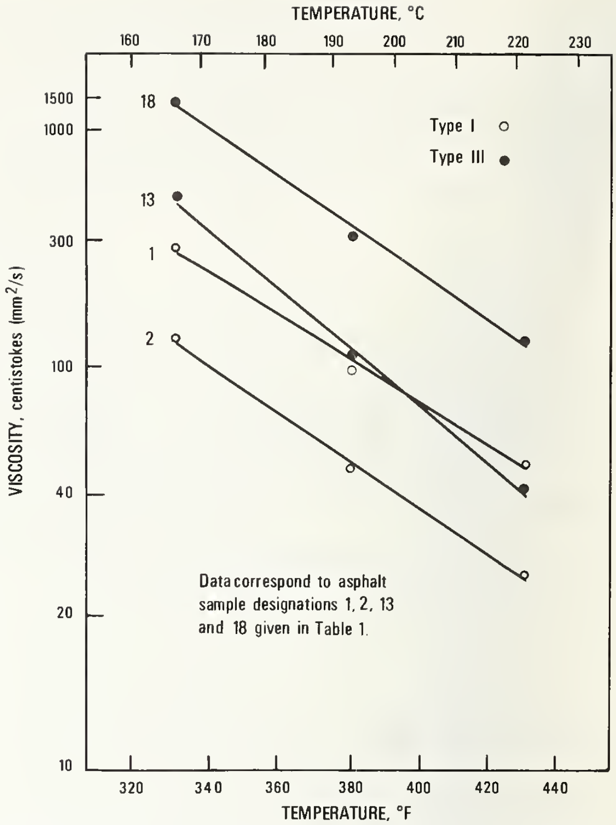

FIGURE 5. *Plots of the log log viscosity versus the log absolute temperature for the most viscous and least viscous Type I and Type III asphalts given in table 1.*

The viscosities of the Type I and Type III asphalts used to prepare the roofing membrane specimens in the field were measured at 25 °F (14°C) increments over a range from 325 to 450 °F (163 to 232°C). The viscosities were determined for asphalt samples which were collected from the heating kettles both before and after mopping. The viscosities of these asphalts corresponding to the temperatures noted above are given in table 2 and illustrated graphically in figure 6. Figure 7 shows that plots of the log log viscosity versus the log absolute temperature for the asphalt samples collected before mopping approximated straight lines.

The values of the viscosities of the asphalts corresponding to the temperatures listed in tables 1 and 2 are the average of three measurements. The relative standard deviation for each average value of viscosity given in tables 1 and 2 was 3 percent or less except for four values given in table 1. The relative standard deviations for sample 4 at 330 °F (166°C), sample 16 at 330 °F (166°C), sample 9 at 330 °F (166°C) and sample 9 to 430 °F (221°C) were 4, 5, 7 and 8 percent, respectively.

The results indicated a wide range of asphalt viscosities at a given temperature. This range decreased with an increase in temperature. The Type III asphalts were in general more viscous than the Type I asphalts at a given temperature. The viscosity-temperature relationships indicated that the Type III asphalts were in general more temperature susceptible than the Type I asphalts.

3.2. Measurement of Interply Asphalt Thickness

The interply thicknesses of asphalt as a function of the application temperatures are given in tables 4 and 5 and plotted in figure 8. The values of interply thickness for each membrane specimen represent the average of 24 measurements. In cases where two comparable membrane specimens were mopped at the same temperature, the interply thicknesses given in tables 4 and 5 represent the average values obtained from the two specimens.

The mean relative standard deviation of the average interply thickness determinations given in tables 4 and 5 was 31 percent. Eighty percent of the relative standard deviations for these determinations fell within the range of 15 to 45 percent. The minimum and maximum relative standard deviations were 9 and 61 percent, respectively.

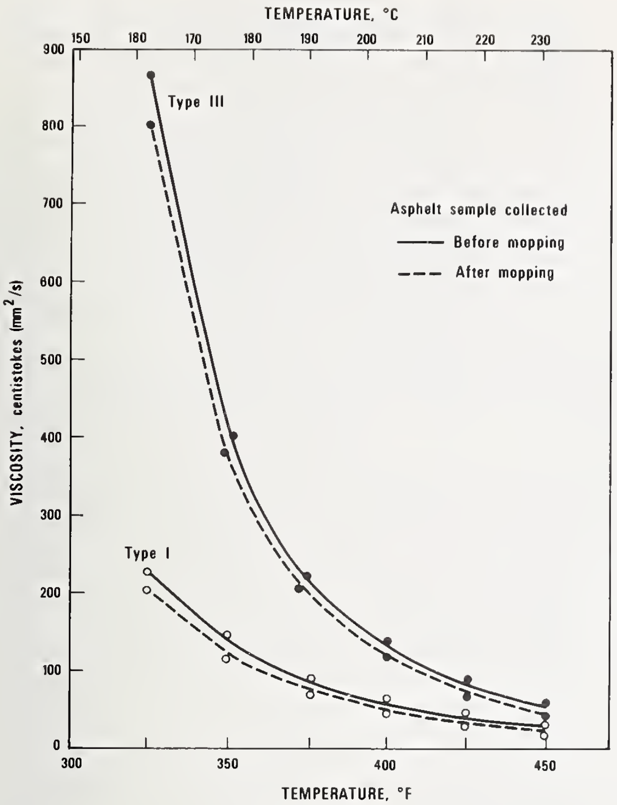

FIGURE 6. *Viscosity-temperature relationships of the asphalts used in the preparation of roofing membrane specimens.*

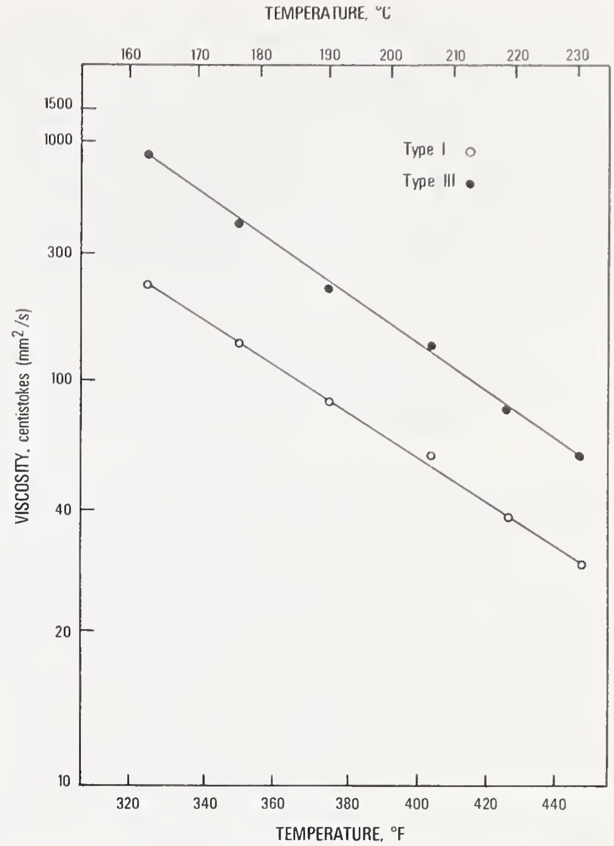

FIGURE 7. *Plots of the log log viscosity versus the log absolute temperature for the asphalt samples collected before mopping.*

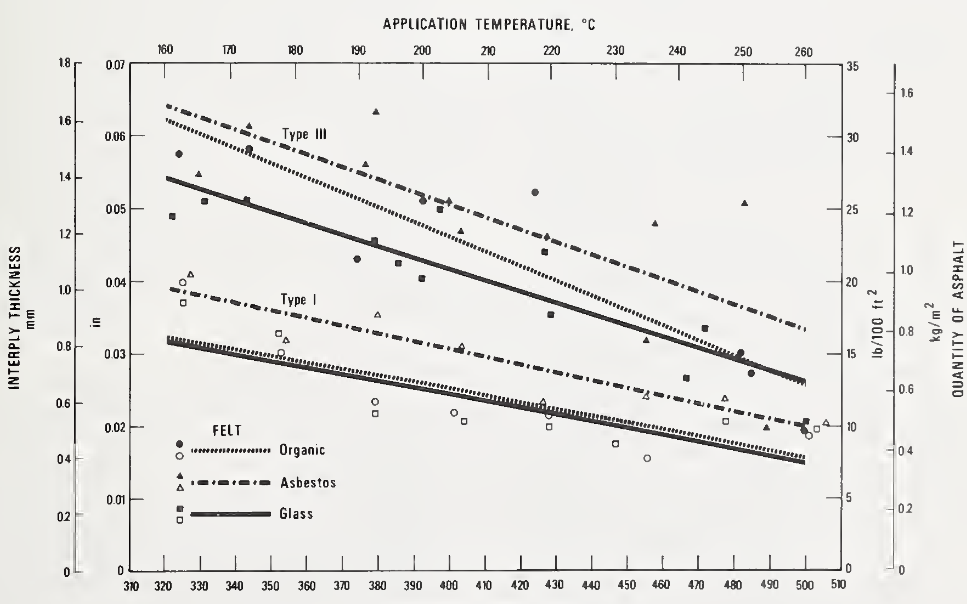

FIGURE 8. *Interply asphalt thickness as a function of the application temperature.*

The lines in figure 8 were obtained from linear regression analyses using the data from tables 4 and 5 for each type of membrane. From this figure it can be seen that at a given temperature the interply asphalt thickness was greater for the Type III asphalt than for the Type I. With an increase in application temperature, the interply thickness decreased. The type of felt appeared to affect the asphalt thickness. For either Type I or Type III asphalt, the interply thickness was in general greater for the asbestos felts than for the organic and glass felts.

4. Discussion of Results

4.1. Viscosity of Roofing Asphalts at the Application Temperature

Two of the three temperatures at which the viscosities of the asphalts listed in table 1 were measured, 380 °F (193°C) and 430 °F (221°C), were within the range normally recommended for application [5, 6]. The third temperature, 330 °F (166°C), was purposely chosen to be slightly lower than the normally recommended minimum application temperature of 350 °F (177°C).

It can be seen from the data in table 1 and figure 4 that there was a wide range in viscosities of both Type I and Type III roofing asphalts for each of the three temperatures. For the Type I asphalts, the values of viscosity ranged from 124 to 275 centistokes (mm^2/s) at 330 °F (166°C), 48 to 98 centistokes (mm^2/s) at 380 °F (193°C) and 24 to 48 centistokes (mm^2/s) at 430 °F (221°C). For each temperature the highest value of viscosity was approximately twice the lowest value.

The difference between the highest value of viscosity and the lowest value for each temperature was greater for the Type III asphalts than for the Type I asphalts. For the Type III asphalts the values of viscosity ranged from 456 to 1383 centistokes (mm^2/s) at 330 °F (166°C), 104 to 322 centistokes (mm^2/s) at 380 °F (193°C) and 41 to 124 centistokes (mm^2/s) at 430 °F (221°C). The highest value of viscosity for the Type III asphalt was approximately three times greater than the lowest value for each of the three temperatures.

The wide range of viscosities of roofing asphalts at their application temperatures is significant and must be considered in the fabrication of built-up roofing. Empirical tests such as softening point and penetration now used for the classification of roofing asphalts are essentially useless to indicate flow behavior in the range of application temperatures. The softening points given in table 1 fall into a narrow range for each type of asphalt, in contrast to the wide range of viscosities. This can be seen from the plot of softening point versus viscosity at 380 °F (193°C) in figure 9 which indicates that there is no apparent relationship between these parameters. For the Type I asphalts, there appears to be no apparent relationship between penetration and viscosity at 380 °F (193°C), as shown in figure 10. For the Type III asphalts there appears to be a relationship between these parameters. However, statistical

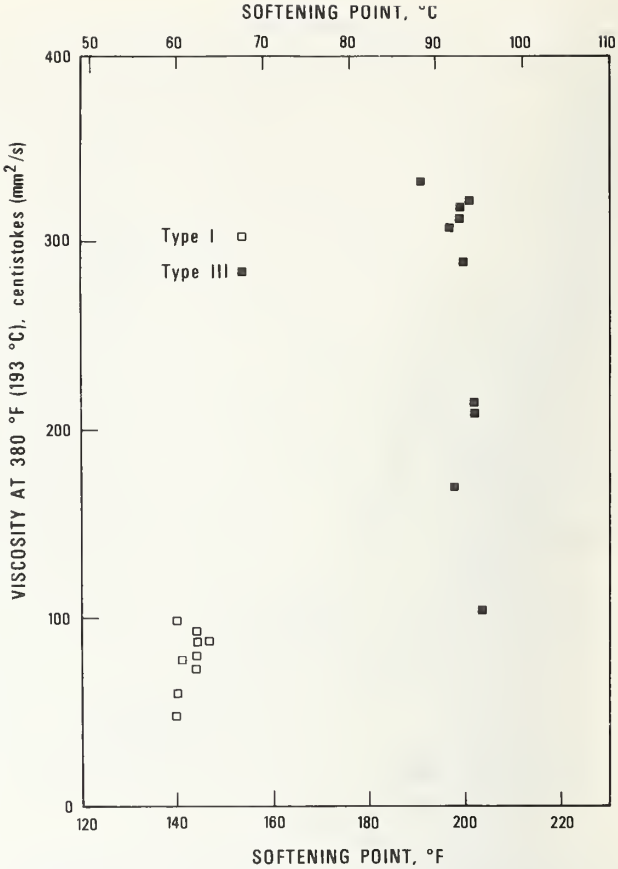

FIGURE 9. *Relationship between softening point and viscosity of asphalt at 380 °F (193° C).*

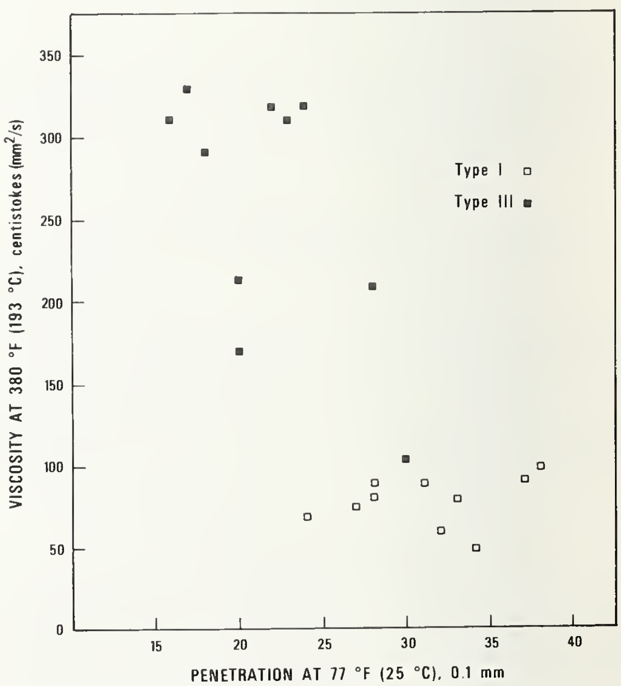

FIGURE 10. *Relationship between penetration and viscosity at 380 °F (193°C) for typical roofing asphalts.*

analysis of the limited data showed that penetration could not be used as a reliable measure of viscosity.

Because of the wide range of viscosities within a type and between types, asphalt should not be applied at an empirically chosen temperature but at a temperature selected according to viscosity to achieve proper flow during application. The data indicate that asphalts within a type should not necessarily be applied at the same temperature. The data further indicate that Type III asphalt should in general be applied at higher temperatures than Type I asphalt. It is noted that for one of the Type III asphalts, number 13, the viscosities at 380 °F (193°C) and 430 °F (221°C) were about the same values as those for some of the Type I asphalts, in spite of the fact that the softening point of asphalt number 13 was about 60 °F (33°C) higher than those of the Type I asphalts.

Figure 4 shows, as expected, that the viscosity of the asphalt decreases with an increase in temperature. The decrease in viscosity with an increase in temperature was less for the Type I asphalts than for the Type III asphalts. The Type I asphalts included in this study were less susceptible to temperature change than the Type III asphalts. This may be important, particularly if an asphalt is highly temperature susceptible, because a slight decrease in application temperature may increase the viscosity above that recommended for proper application.

The viscosities of the Type I and Type III asphalts used to prepare the roofing membrane specimens fell within the ranges of the viscosities of the typical roofing asphalts obtained from various sources. Values of viscosity, softening point and penetration for the asphalt samples collected before and after mopping membrane specimens are given in table 2. There was a slight decrease or fallback in the viscosity of both the Type I and Type III asphalts during the course of preparing the membrane specimens, as shown in figure 5. There was no significant change in the softening point or penetration of Type III asphalt and only a 2 °F (1°C) decrease in the softening point of the Type I asphalt. The viscosity fallback was not extensive but it occurred during a 3 hour period. The slight fallback in viscosity could be attributed to overheating of the asphalt which was necessary in this experiment. In order to obtain the temperature of 500 °F (260°C) in the mopping bucket as required by the experimental program, the temperature of the asphalt in the kettle reached 575 °F (302°C).

4.2. Interply Asphalt Thickness as Related to the Application Temperature

In the fabrication of built-up roofing membranes, adequate interply thickness of asphalt and adhesion between piles of felt depend to a large extent on proper application of the asphalt. Adequate interply thickness requires that the asphalt has a certain viscosity during application. Since a test method to measure asphalt viscosity precisely in the field was not available, temperatures of the asphalt at the time of application were related to subsequent laboratory determinations of viscosity. Interply thicknesses were readily measured in the laboratory. It would have been desirable to measure the interply adhesion of the membrane specimens in evaluating proper application of the asphalt; however, no established test method was available.

The relationships between interply asphalt thickness and application temperature are shown in figure 8 for the six types of membranes fabricated with organic, asbestos and glass felts and Type I and Type III asphalts. As expected, the interply thickness decreased with an increase in application temperature. The interply thicknesses for the 95 membrane specimens, tables 4 and 5, ranged in general from 0.02 to 0.06 inches (0.51 and 1.52 mm). The thicknesses of Type III asphalt were greater than the thicknesses of Type I in membranes containing all three felts over the application temperature range.

For both Type I and Type III asphalts, the interply thicknesses were in general greater in the asbestos membranes than in the organic and glass membranes. The interply thicknesses of Type III asphalt in the organic membanes were greater than in the glass membranes, whereas the interply thicknesses of Type I asphalt in membranes containing these felts were essentially the same. The authors have not investigated the reasons for the apparent differences in asphalt thickness between membranes fabricated with the three different felts and the same type of asphalt. It was possible that the organic and glass felts absorbed more asphalt during application than the asbestos felts.

4.3. Interply Asphalt Thickness as Related to the Viscosity at Application

The important property of the asphalt that determines the interply thickness is viscosity and not the temperature during application. The interply thicknesses of the membrane specimens were related to the viscosities of the asphalts at their application temperatures. The interply thickness-viscosity relationship was determined from the thickness-temperature relationships of the membrane specimens and the viscosity-temperature curves of the asphalts used to fabricate the membrane specimens.

Interply thickness data were obtained for asphalt application temperatures ranging from approximately 325 °F (163°C) to 500 °F (260°C). It was not possible to measure the viscosity of the asphalts above 450 °F (232°C.). In order to have viscosity-temperature data over the same temperature range as the interply thickness-temperature data, it was necessary to extrapolate the viscosity-temperature curves (fig. 6) to 500 °F (260°C). Using the NBS computer, least squares curves were fit to the viscosity-temperature data between 325 °F (163°C) and 450 °F (232°C), and values of viscosity were predicted for asphalt temperatures above 450 °F (232°C). Viscosity-temperature data for the asphalt samples collected before mopping were used in the least square analyses. The computer-generated equation for the viscosity-temperature relationship for the Type I asphalt determined from the least square fit was:

$$\log \eta = 0.0013846535 - 153.25223Z + 224359530.0Z^3 \quad (1)$$

where η = viscosity and $Z = 1/(°C + 273.15)$.

For the Type III asphalt the computer generated equation was determined to be:

$$\log \eta = -0.0096243870 - 298.62132Z + 300228880.0Z^3. \quad (2)$$

Equations (1) and (2) were used to calculate the viscosities of the asphalts at the temperatures at which the membrane specimens were prepared. For obtaining the calculated values of asphalt viscosity, these equations were preferred over the method described in ASTM D341–74 [10] and illustrated in figure 7. These calculated values of viscosity are given in tables 4 and 5 along wtih the corresponding application temperatures and interply thicknesses. Values of interply thickness as related to the asphalt viscosities are illustrated graphically in figure 11.

It can be seen from figure 11 that a linear relationship between interply thickness and viscosity did not exist over the viscosity range of 0 to 1000 centistokes (mm^2/s). In the viscosity range of 500 to 1000 centistokes (mm^2/s) there was no increase in interply thickness with an increase in viscosity. The data in the viscosity range of 500 to 1000 centistokes (mm^2/s) represented Type III asphalt applied at temperatures from approximately 325 °F (163°C) to 350 °F (177°C). These temperatures are below the minimum recommended application temperatures for Type III asphalts [5, 6]. Since the data in the viscosity range of 500 to 1000 centistokes (mm^2/s) were not obtained from recommended application temperatures and the asphalt was too viscous for proper application, these data were not considered in subsequent analyses. Figure 12 presents the interply thickness-viscosity data over the viscosity range of 0 to 250 centistokes (mm^2/s). The straight line in this figure determined from a linear regression analysis was obtained by treating all data as being equivalent. It was assumed that visocsity governed the interply thickness of asphalt. Differences arising from the type of felt or asphalt were not considered in this analysis. These differences and their effect on interply thickness are examined in the Appendix.

5. Viscosity Criterion for the Application of Roofing Asphalt

The interply thickness-viscosity relationship shown in figure 13 was used as the basis for the recommended application viscosity criterion. In 1972 Cramp, Cullen and Tryon [4] recommended that the optimum application rate for asphalt in the fabrication of built-up membranes be within the range of 15 to 20 pounds per 100 square feet of area (0.73 to 0.98 kg/m^2). This application rate corresponds approximately to an interply thickness of 0.03 to 0.04 in (0.76 to 1.02 mm). As shown in the shaded area of figure 13, a viscosity range of about 60 to 145 centistokes (mm^2/s) corresponds to the interply thickness range of 0.03 to 0.04 in (0.76 to 1.02 mm). Based on the results of this study the viscosity range, 60 to 145 centistokes (mm^2/s), is the recommended optimum viscosity range for the application of roofing asphalt in built-up membranes. In practice this viscosity range can be taken as 50 to 150 centistokes (mm^2/s). The range refers to asphalt viscosity at the time of membrane fabrication and not

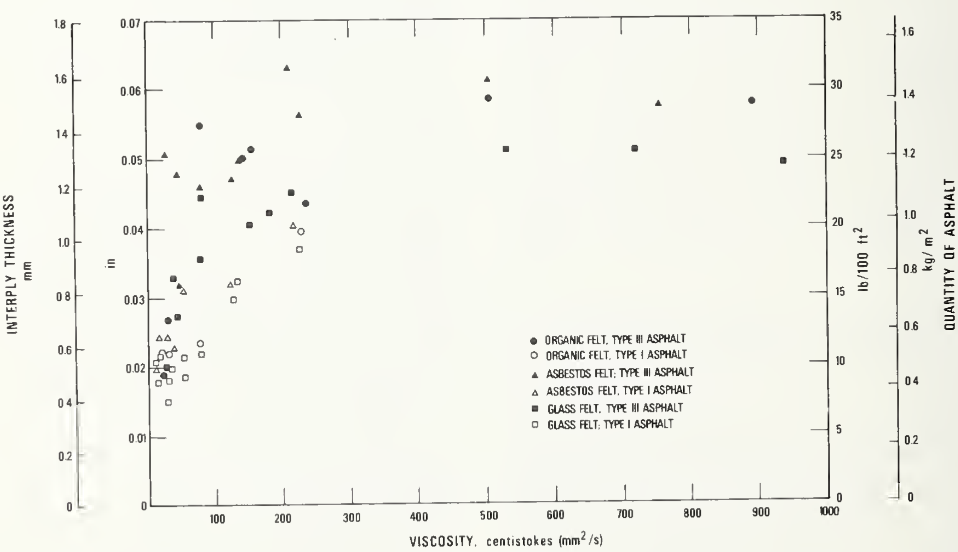

FIGURE 11. *Relationship between interply asphalt thickness and viscosity for the viscosity range of 0 to 1000 centistokes (mm^2/s).*

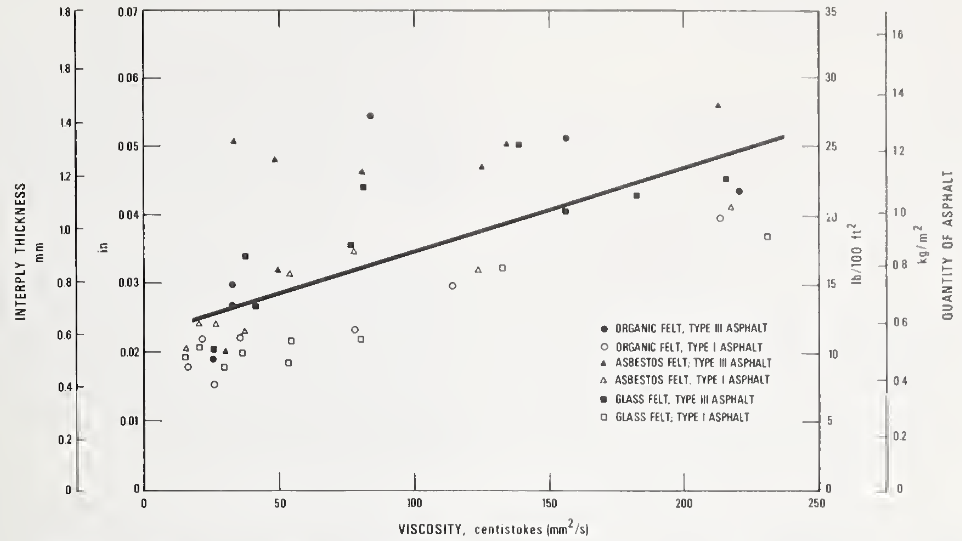

FIGURE 12. *Relationship between interply asphalt thickness and viscosity for the viscosity range of 0 to 250 centistokes (mm²/s).*

the viscosity of the asphalt in the kettle. To maintain the application viscosity range, consideration should be given to environmental conditions such as ambient temperature and wind speed.

It is realized that the application rate of asphalt in the fabrication of built-up roofing membranes recommended by the roofing industry is normally 15 to 25 pounds per 100 square feet (0.73 to 1.2 kg/m²). Such an application rate would extend the viscosity range beyond the optimum to 220 centistokes (mm²/s), as shown by the dashed lines in figure 13. It is recommended, however, that the viscosity criterion should be based on the optimum application rate.

It is not necessary to measure the viscosity of the asphalt at the job site in order to apply the viscosity criterion. The viscosity criterion can be used as the basis for determining the proper application temperature range for any roofing asphalt, provided that the viscosity-temperature relationship is known. An example of using the viscosity criterion to determine the application temperature range is illustrated in figure 14 for the two asphalts used to fabricate the membrane specimens in this investigation. The shaded area in this figure indicates the recommended viscosity criterion of 50 to 150 centistokes (mm²/s). The application temperature ranges for the asphalts are determined by

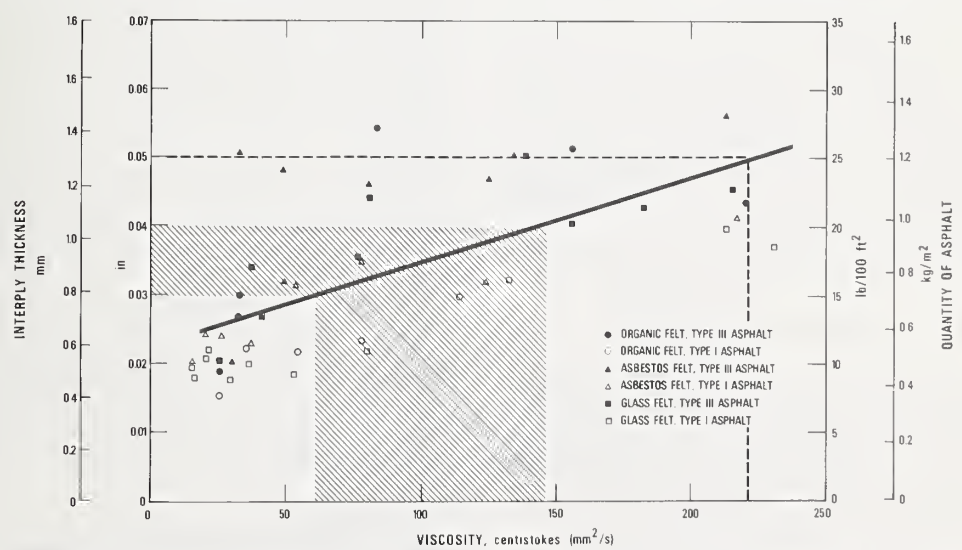

FIGURE 13. *Interply thickness-viscosity relationship used as the basis for the recommended application viscosity criterion.*

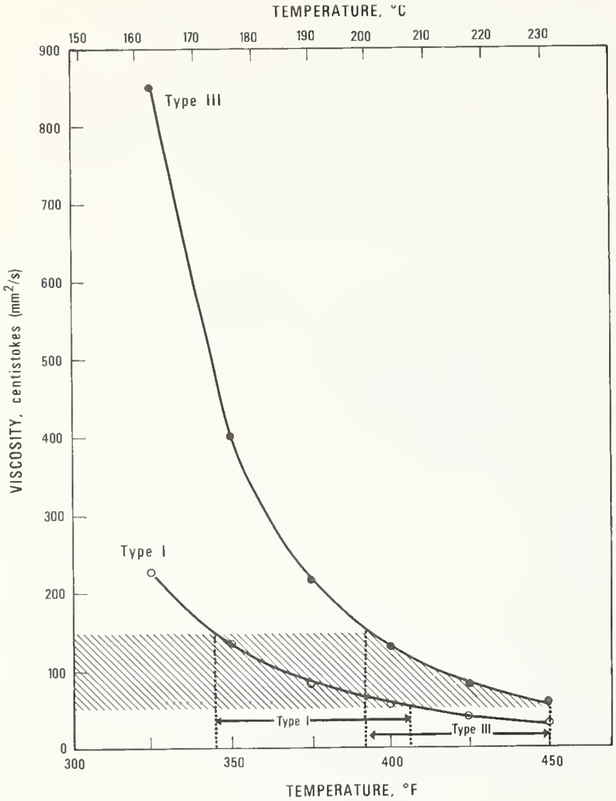

FIGURE 14. *An example of the use of the viscosity criterion for determining the application temperature ranges for the asphalts collected before mopping given in table 2.*

the intercepts of the shaded area with the viscosity-temperature curves. For the Type I asphalt the recommended temperature range is about 345 to 405 °F (174 to 207°C), and for the Type III asphalt the temperature range is about 390 to 450 °F (199 to 232°C). Again, these recommended temperature ranges refer only to the application temperature and not to the kettle temperature. It is emphasized that these application temperature ranges apply only to the Type I and Type III asphalts used to prepare the membrane specimens. Because of the wide range of viscosities for a given type of asphalt (table 1), it is necessary that the viscosity-temperature relationship of an asphalt be known prior to application.

6. Recommendations

This study investigated the viscosities of typical roofing asphalts at their application temperatures and the relationship between interply asphalt thickness of roofing membrane specimens and the viscosity of the asphalt at the time of application. Based on this study the following recommendations are made:

(1) Roofing asphalts should not be applied between empirically determined temperature limits. Asphalts of the same type, as determined by softening point and penetration, may have widely varying viscosities over the application temperature range.

(2) Roofing asphalts should be applied between temperature limits which are based on the viscosities of the asphalts over the application temperature range. Viscosity is the property which governs the flow of asphalt during fabrication of built-up roofing membranes.

(3) The optimum viscosity of the asphalt at the time of application should be within the range 50 to 150 centistokes (mm^2/s). This viscosity range corresponded to an application rate of approximately 15 to 20 lb/100 ft^2 (0.73 to 0.98 kg/m^2). To maintain this viscosity range at application, consideration should be given to environmental conditions, such as ambient temperature and wind speed.

(4) The viscosity-temperature relationship should be determined for each roofing asphalt for the application temperature range prior to application. Using this relationship and the optimum viscosity range of 50 to 150 centistokes (mm^2/s), the temperature range for applying each asphalt can be determined. It is not necessary to measure the viscosity of the asphalt at the job site.

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8. Appendix. Relationship Between Asphalt Thickness and Viscosity Examined in More Detail

The optimum range of viscosity over which the hot asphalt should be applied has been given as 50 to 150 centistokes (mm^2/s). This range was based on the interply thickness-viscosity relationship given in figure 12 for which all data were treated as equivalent. No distinction was made between interply thickness data for membranes fabricated from the different types of of felt and asphalt.

If a distinction is made between the types of felt and not between the asphalts, an interply thickness-viscosity relationship can be determined for membranes containing each type of felt. It can be seen from these relationships in figure 15, determined by regression analyses, that the asphalts applied at a given viscosity resulted in greater interply thicknesses in the asbestos felt membranes.

The data were also examined by making a distinction between the types of asphalt and not between the types of felt. The relationships shown in figure 16, as determined by regression analyses, indicated that greater interply thicknesses were observed in membranes fabricated from Type III asphalt. This difference in interply thickness may possibly be attributed to the Type III asphalt being more temperature susceptible than the Type I. From figure 6 it can be seen that a small decrease in temperature caused a larger increase in the viscosity of the Type III asphalt than for the Type I particularly at the lower temperatures.

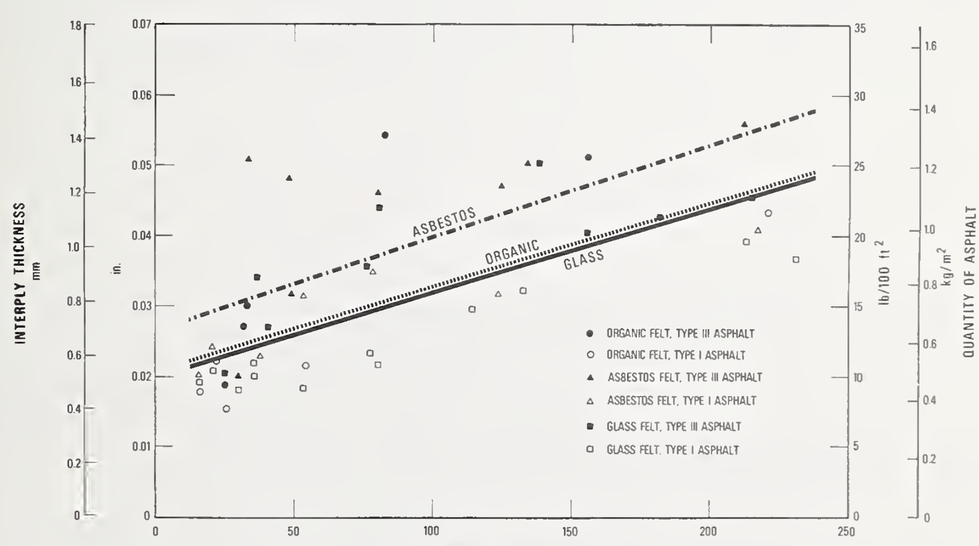

FIGURE 15. *Relationships between interply thickness and asphalt viscosity for the three types of membranes.*

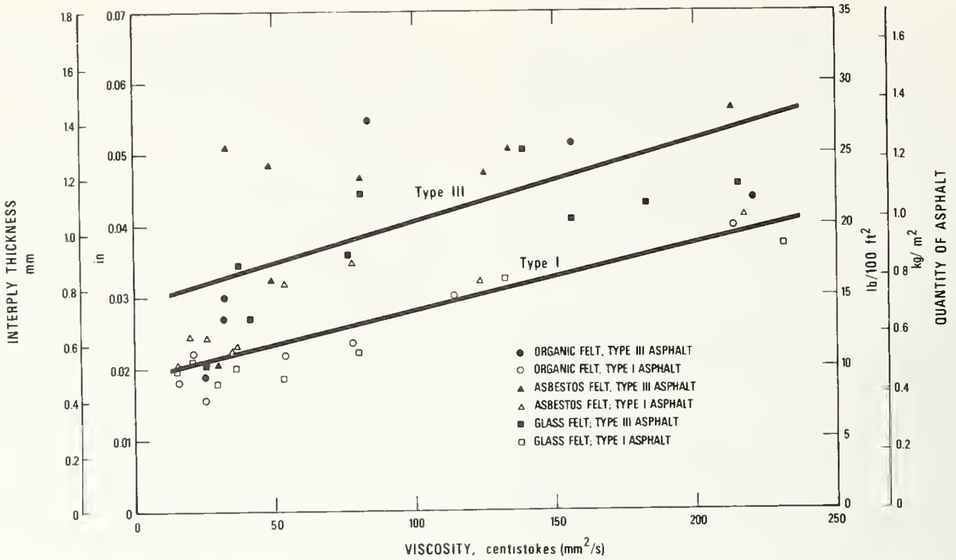

FIGURE 16. *Relationships between interply thickness and asphalt viscosity for the two types of asphalt.*

The relationship between interply asphalt thickness and viscosity will depend to some extent on the rate of cooling of the hot asphalt during application. The interply asphalt thicknesses were determined from membrane specimens fabricated indoors at 60 °F (16°C). Environmental conditions other than those encountered in this investigation may result in an interply thickness-viscosity relationship different than that shown in figure 10 because of differences in the rate of cooling of the asphalt. Conditions affecting the cooling rate of asphalt include air temperature, wind speed, substrate temperature and the specific heat of the substrate.

The type of construction technique may also affect the interply thickness-viscosity relationship. The interply thickness of roofing membranes may be affected by brooming, unrolling of felts, and the type of equipment for spreading asphalts and laying felts.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The optimum range of viscosity over which hot asphalt should be applied in the fabrication of built-up roofing membranes was determined to be 50 to 150 centistokes (mm^2/s). This viscosity range was based on the relationship between interply thickness and application temperature of asphalt obtained from roofing membrane specimens fabricated in the field. Because laboratory measurements showed a wide range of viscosities for roofing asphalts of the same type over their application temperature ranges, it was recommended that asphalts be applied at temperatures based on viscosity and not empirically determined temperature limits. In practice, the viscosity-temperature relationship should be determined for each roofing asphalt for the application temperature range prior to use. Using this relationship and the optimum viscosity range, the temperature range for applying each asphalt can be determined.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Application temperature; asphalt; built-up roofing; interply thickness; roofing membranes; viscosity.

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